DESIGN PROTOTYPING FOR MANUFACTURABILITY

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Abstract

Prototyping is one of the best ways to ensure Design for Manufacturability (DFM), and to bring all areas of a company involved in getting a product to market to come together and work for a common goal. Decisions made during this design stage will ultimately determine the cost of producing the product. In this study, the authors evaluated the concept of concurrently designing a part, modifying it, and further evaluating the design through prototyping to ensure that the part can be efficiently and effectively manufactured. Presented here is the examination of the interrelationship between Computer-Aided Design and Computer-Aided Manufacturing (CAD/CAM) for designing a part and the ability to make modifications (at no expense to functionality) for preparing the part for manufacturability.

Introduction

Among others elements, manufacturing competitiveness requires sustained growth and earnings by building customer loyalty through the creation of high-value products in a very dynamic global market. Not only are most companies under pressure to develop products within rapidly shrinking time periods, companies must also build products, which can be manufactured, produced, serviced and maintained. In accomplishing this task, it is evident that one must strive for functional design, while keeping in mind that a functional design must be manufacturable and reliable. Product designers, therefore, have the responsibility for a product that meets all the characteristics of functionality, reliability, appearance, and cost effectiveness.

Prior to the concept of design for manufacturability (DFM), designers had worked alone or in the company of other designers in isolated areas dedicated to such operations. Typically, completion of the design would be sent to manufacturing without much interaction, leaving manufacturing with the option of struggling with a part that is not designed for manufacturability or rejecting it only when it is too late to change the design. Hence, successful product development requires tools like DFM [1].

The most efficient fashion by which manufacturability can be secured is to develop the part in multi-functional teams with early and active participation of all involved, as shown in Figure 1. That is, the concept of design for manufacturability must include some elements of concurrent engineering, where each of the modifications of a designed part represent a transformational relationship between specifications, outputs and the concept the manufacturing represents [2]. Prasad [2] also asserts that "At the beginning of the transformation, the modifications of the design are gradually in abstract forms. As more and more of the specifications are satisfied, the product begins to take shape." Existing approaches to evaluating product manufacturability can be classified as: 1) direct or rule-based approaches [3] or 2) indirect or plan-based approaches [4]. The direct approaches have been considered to be more useful in domains such as near-net-shape manufacturing and less suitable for machined or electronics components, where interactions among manufacturing operations make it difficult to determine manufacturability of a design directly from the design description [5].

A product begins with a need, which is identified based on customer and market demands. The product goes through two major processes from conceptualization of the idea to the finished product: the design process and the manufacturing process. These two functions are the main areas in any production setting and, therefore, the interrelationship between them must always be of paramount importance to any product designer. Crow [6] asserts that design effectiveness is improved and integration facilitated when:

- Fewer active parts are utilized through standardization, simplification and group technology retrieval of information related to existing or preferred products and processes.
- Producibility is improved through incorporation of DFM practices.
- Design alternatives are evaluated and design tools are used to develop a more mature and producible design before release for production.
- Product and process design includes a framework to balance product quality with design effort and product robustness.

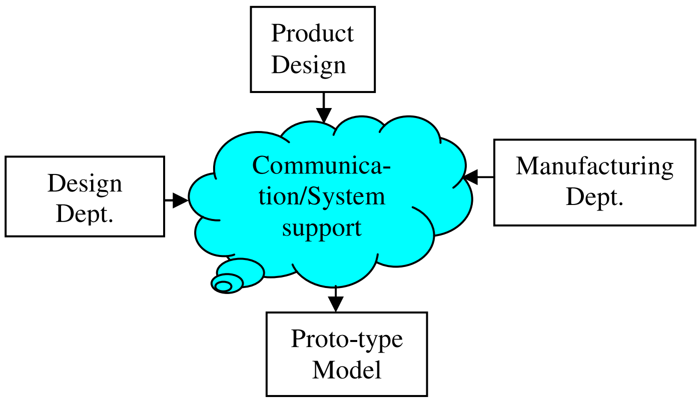


Figure 1. Partial Concurrent Product Design Phase

Prototyping is a simplification of a product concept. It is tested under a certain range of conditions to approximate the performances constructed to control possible variability in the tests, and is ultimately used to communicate empirical data about the part so that development decisions may be made with high confidence at reduced risk [7]. Prototyping evolves from computer-aided engineering (CAE). The question again is who should decide on prototyping the design.

Computer-Aided Design/ Manufacturing (CAD/CAM)

Creating a CAD file interface increases the productivity of a designer, improves the quality of design and establishes a manufacturing database. Initially, CAD systems were conceived as automated drafting stations in which computer-controlled plotters produced engineering drawings. CAM, on the other hand, was developed to effectively plan, manage, and control manufacturing functions. According to Rehg and Kraebber [8], the evolution of CAD/CAM technology has made it possible to integrate many technical device areas that have for so long developed separately. CAD/CAM is the integration of design and manufacturing activities by means of computer systems. Methods used to manufacture a product are a direct function of its design and, therefore, the integrations of the two systems must always be considered when designing a product for manufacturability. CAD/CAM establishes a direct link between product-design and manufacturing departments. The goal of CAD/CAM is not only to automate certain phases of design and certain phases of manufacturing, but also to automate the transition from design to manufacturing.

In this study, the interrelationship between Computer-Aided Design and Computer-Aided Manufacturing (CAD/CAM) was explored to concurrently design a product and produce a prototype of the design to ensure manufacturability that is efficient in terms of cost and appearance. For simplicity, the design was based on operations performed on general-purpose equipment such as Computer Numerically Controlled (CNC) machines. This was selected in order to enhance the progressive design of the product and because of such advantages as reduced lead-time, process optimization, and reduced setup and change-over times.

In a concurrent design environment, all departments involved work together by providing information pertinent to each department to the designer in order to solve the design problem. Through this cooperation, the designer has access to information from these departments at any time so that an evaluation of the design can be performed. In order to effectively do this, necessary information includes a manufacturability assessment, total amount of materials to be removed, desired tolerance and surface finish, cutting parameters and the machining time. By concurrently including both the manufacturing and production departments, the designer will be conversant on the machine floor, that is, capabilities of available machines, cutting tools and also the materials, dimensions, tolerances and surface finish. The information in serial engineering flows in succession from phase to phase [9]. This information will be compared to enhance the manufacturability of design feature.

Problem Definition and Approach

The fundamental reason for designing a part is so that it can eventually be manufactured. In a traditional design cycle, manufacturing is often considered just a step that comes only after the design is complete (Figure 2).

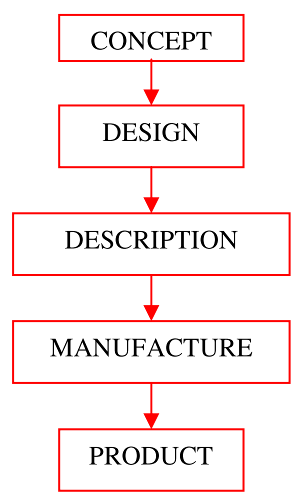


Figure 2. CAD/CAM Current State

With this approach, it becomes very difficult to coordinate the activities of those individuals involved in getting a product to the marketplace, and measure manufacturability to achieve overall system objectives. It cannot be denied, then, that the best way to achieve manufacturability is when both parties work together from the inception to the end of the design, as shown in Figure 3. Even though the designer works to bring the part into a position to be manufactured, he/she must maintain constant communication with manufacturing.

Manufacturing can be a major factor in design thinking and also provide such information as the state of manufacturing resources that might not otherwise be known to the designer. This cooperation helps identify manufacturing problems at the design stage, thereby minimizing the total cost of the part, improving the quality, and accelerating the introduction of the product into the marketplace. Certain

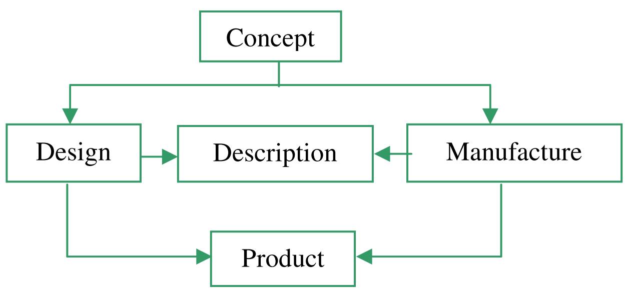


Figure 3. CAD/CAM Proposed State

design decisions greatly influence design for manufacturability and associated costs, and it is imperative that a designer understands the impact of these decisions early in the design process.

It is evident that the easier a part is to manufacture, the easier it will be for the part to respond to elements of interchangeability. That is, putting one part together with other parts that have been designed to the same criteria ensures easy assembly. A typical design process for manufacturing systems is often grouped into three stages. The first stage determines and characterizes three key components of the system: products produced, machines used, and the material-handling system used. For each component, designers usually have many alternatives, each alternative with different features and costs. Once the alternatives of the three components have been decided upon and characterized, the second stage is to integrate them and generate design alternatives. The third stage is to evaluate these design alternatives to see if they are economically justified in terms of manufacturability.

Efforts have been made to replace the human expert designer with artificial intelligence, neural networks and genetic algorithms [10]. These approaches have shown some potential in some areas but are limited in application. After a thorough analysis of all possible alternatives, the authors feel that design prototyping will bring the two most important departments (design and manufacturing) together as a team. The process considers the modification of the part design, as shown in Figure 4, and evaluates it for manufacturing feasibility [11]. This takes into consideration part design and production requirements that make it easier, more efficient and effective for manufacturability. The prototype considers the selection of a suitable material such that the part is producible in large quantities, and maintainable.

Design Procedure and Discussion

The most elusive part of the term CAD/CAM is that deceptively simple oblique stroke, which links the two halves. Design (CAD) and manufacture (CAM) are best thought of as totally distinct and separate operations (figure 2) performed by different people, in different places, and at different times, using different tools and different skills. Based on this concept, once a design is complete, the designer's work is done. The designer simply hands the finished description of the object over to manufacturing, which uses the information as a guide to manufacture the part and, consequently, transform the concept into a product.

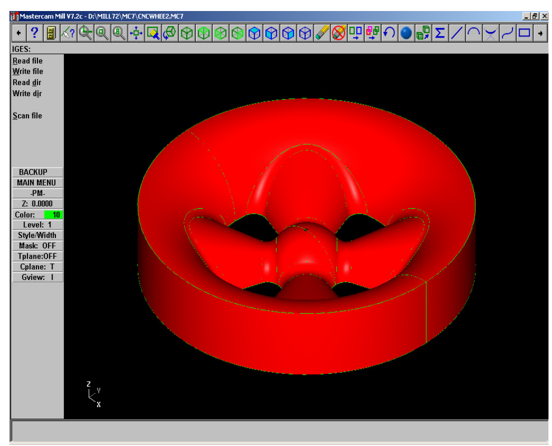


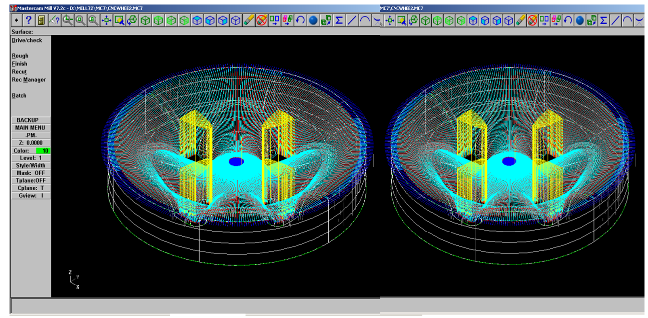
Figure 4. Solid Part Model Design

The process involves two groups, design and manufacturing, that must work together to ensure effective and economic manufacturability of the part. The design process begins with the redesigning of the part translated from the solid model in Figure 4 into the simulated design of Figure 5(a), using I-DEAS (Integrated Design Engineering Analysis Software). I-DEAS is solids-based, simulation-driven software that provides full-function design analysis, drafting, testing and Numerical Control (NC) programming in support of mechanical design automation. It is a complete Mechanical Computer-Aided Engineering (MCAE) system. However, in order to enhance flexibility and adaptation to other systems, and manufacture a prototype of the part, the NC codes for this design were developed using the Mastercam (CAM) software. Mastercam was used in order to enhance the integration of two different software packages in order to increase flexibility and still maintain the level of concurrency needed to keep both design and manufacturing fully involved. Had this process been completely carried out in I-DEAS, the level of involvement of manufacturing would still have been reduced to a minimum. The use of Mastercam provided the concurrency and the interaction needed between design and manufacturing. In providing the most efficient design, the design meets all geometric specifications to within the parameters of resources available.

The initial part was designed following all geometric dimensioning and specifications. The part drawing was saved in I-DEAS, while the process moved to Mastercam software, where the part design was exported from I-DEAS as an IGES (Initial Graphics Exchange System) file to Mastercam. Mastercam gives programmers the power to capture their knowledge and build on their experiences. Using this software, the programmer has available the tools to modify any element of the part and immediately get updated tool paths without starting over.

In Figure 5a, which is the original part presented in Figure 4, the tool path was developed and simulated, and the result was saved and the part modified. The two designs were functionally identical. However, by simply reworking from two components to one, manufacturability was enhanced and manufacturing costs were reduced by more than 42 percent, as determined from code and time savings. The reduction of individual components made the final part easier to manufacture. After the original part was completed, the part was imported to Mastercam and NC codes were generated. Initially, the program resulted in 52,000 blocks of NC code being generated, and took 9.38 minutes of simulation time. After several iterations, the codes were reduced to 30,000 blocks and simulation time reduced to 4¾ minutes.

In the actual prototyping of the part, the CNC milling center was used. The manufacturing times for both designs—initial and modified—were measured during processing. For the initial stage of milling, the time observed was 4.0 hours, while a time of 2.37 hours was recorded for the modified version.



(a) **(b)**

Figure 5. Part Design with Toolpaths Simulation

The design process can be viewed as a sequence of decisions performed iteratively based on uncertain information. Beginning from the earliest phases of the process, decisions were made that define the overall design strategies and their impact on manufacturing feasibility. In order to further enhance concurrency, flow between design and manufacturing, and to improve the design and manufacturing efficiency, the evaluation of tooling, material, clamping methods and machine setup were being performed, while the design was still being concluded. The resulting prototype, which was made out of wax, is shown in Figure 6.

Figure 6. Actual Prototype

Conclusion

Design for manufacturability (DFM) is the process of proactively designing products to optimize all of the manufacturing functions, and to assure the best cost, quality, reliability, regulatory compliance, safety, time-to-market, and customer satisfaction. Early consideration of manufacturing issues shortens product development time, minimizes development cost, and ensures a smooth transition into production for quicker time-to-market.

The process described here about design and prototyping for manufacturability, looks at the intersection of CAD and CAM and develops a process in which a part is designed and all necessary codes to manufacture it are generated and evaluated for easy manufacturability. Subsequent geometry changes are made until the part can be manufactured efficiently and economically, employing the integration of two software packages that respectively capture part design and production.

In order to avoid pitfalls, design and manufacturing engineers must work together, understand and use many tools of modern product development and design for manufacturability. It is no longer acceptable in the modern manufacturing environment for any of these individuals to work in isolation.

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